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Comparing petro-plastic and bioplastics supply chains: Firm-level insights from the packaging industry

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ABSTRACT

This paper empirically compares supply chain practices between petro-plastic and bioplastic carrier-bag industries. It examines how sourcing, production, and distribution differ between established fossil-based chains and emerging compostable alternatives, and how these differences affect operational performance and transition feasibility. A qualitative comparative design was applied to two product-based supply chains, petro-plastic and bioplastic carrier bags—within the packaging industry. Evidence was derived from 17 semi-structured interviews with senior executives, factory managers, buyers, and association representatives across Europe, Southeast Asia, the Middle East, and Australasia. Data were analyzed using Braun and Clarke's six-step thematic approach, identifying three core themes: sourcing practices, production configurations, and distribution structures. The results reveal pronounced divergences in sourcing stability, process maturity, and distribution scalability. Petro-plastic chains benefit from global supplier networks and cost efficiency, while bioplastic chains face supply constraints, quality variability, and regionalized logistics. Managers must reconfigure sourcing, production, and logistics capabilities to align efficiency with sustainability compliance. This study advances sustainable supply chain literature by providing firm-level comparative evidence on how material transitions reshape operational practices in the packaging sector.

1. Introduction

The packaging industry is undergoing one of the most disruptive transitions in its history, driven by regulatory interventions, consumer awareness, and mounting environmental concerns. Single-use petro-plastic carrier bags, once a symbol of low-cost convenience and supply chain efficiency, have become a focal point of global campaigns against plastic waste. Governments worldwide have introduced bans, taxes,

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or restrictions on plastic bags, and retailers have responded with a mix of compliance and voluntary sustainability initiatives (Nielsen et al., 2019). Against this backdrop, bioplastics, particularly industrially compostable carrier bags, certified under EN 13432 or ASTM D6400 standards, have emerged as promising alternatives. Yet, the transition is far from straightforward. The operational realities of bioplastic supply chains remain underexplored, even as expectations rise among policymakers, consumers, and industry stakeholders.

The petro-plastic supply chain paradigm is characterized by maturity, scale, and decades of optimization. Over decades, firms have refined their procurement, production, and logistics practices to deliver efficiency, standardization, and cost minimization across global networks (Hopewell et al., 2009). These practices are supported by stable petrochemical inputs, predictable supplier qualification regimes, and globally integrated distribution channels. By contrast, bioplastic supply chains are emergent, fragmented, and shaped by technological immaturity, inconsistent regulatory frameworks, and ambiguous end-of-life pathways (Peelman et al., 2013). Firms adopting bioplastics face challenges ranging from raw material shortages and certification bottlenecks to unstable customer acceptance and regionalized distribution risks (Di Bartolo et al., 2021). This divergence raises critical questions: how do core supply chain practices differ across these two material paradigms and what are the implications for the scalability of bioplastics.

While sustainable supply chain management (SCM) frameworks have evolved to integrate environmental objectives, existing SCM models remain insufficient for bioplastics. These frameworks were designed around mature, fossil-based systems assuming material stability, predictable standards, and cost-optimized efficiency. Bioplastic transitions, however, involve supply volatility, certification constraints, and process adaptation that challenge these underlying assumptions. As a result, traditional SCM constructs cannot fully explain how firms develop resilience and adapt capabilities in emergent material systems (Golicic & Sebastiao, 2011; Saad et al., 2014).

The academic literature on plastics has largely concentrated on environmental performance assessments and consumer acceptance studies. Life-cycle assessment (LCA) research has compared the ecological impacts of petro-plastics and bioplastics, often highlighting trade-offs between carbon emissions, land use, and waste management outcomes (Papong et al., 2014; Spierling et al., 2018). Parallel research has examined consumer willingness to pay for sustainable packaging, identifying increasing awareness but persistent barriers linked to price sensitivity and skepticism (Dilkes-Hoffman et al., 2019; Filho et al., 2022). This focus on endpoints and impacts, while valuable, creates a critical 'black box' around the firm-level supply chain practices that mediate whether environmental gains can be realized in practice. How firms manage sourcing, certification, production, and logistics during such transitions remain underexplored.

Addressing this gap, the present study draws on comparative SCM and dynamic capabilities theory to explain how firms navigate supply chain transitions under material change. Comparative SCM provides a lens to identify divergences between mature and emergent supply chains, while dynamic capabilities (Teece et al., 1997; Saad et al., 2014) explain how firms sense, seize, and reconfigure resources to manage instability.

Accordingly, this study focuses on the following research objective (RO) and question (RQ):

- RO: Identify and compare core supply chain practices for bioplastic versus petro-plastic carrier-bag supply chains across sourcing and supplier qualification, processing and quality control, inventory and storage, distribution and logistics, compliance and certification, and the operational interface with end-of-life pathways.
- RQ: In what salient ways do core supply-chain practices diverge between established petro-plastic and emerging bioplastic carrier-bag supply chains?

The study draws on a qualitative comparative research design, examining two product-based supply chains within the packaging industry: petro-plastic and bioplastic carrier bags. Data were collected from 17 senior industry informants, including managing directors, factory managers, buyers, and association representatives across Europe, Southeast Asia, the Middle East, and Australasia. This cohort represented a cross-section of petrochemical suppliers, converters, packaging manufacturers, and retailers, enabling a holistic comparison of supply chain dynamics. Thematic analysis (Braun & Clarke, 2006) was employed to extract patterns across interviews, resulting in three dominant sub-themes: sourcing practices, production configurations, and distribution and channel structures.

The findings reveal clear divergences between the two supply chain types. In sourcing, petro-plastic firms benefit from established supplier networks and stable global trade, whereas bioplastic firms rely on a limited number of certified resin suppliers and face quality inconsistencies. In production, petro-plastic operations are technologically mature with low scrap rates, while bioplastic processing involves frequent reconfiguration and certification-driven testing. In distribution, petro-plastics utilize optimized warehousing and global partnerships, while bioplastics operate within fragmented regional networks constrained by shelf-life and cost considerations.

This study contributes to the SCM and sustainable operations literature in three ways. First, it provides one of the few firm-level comparative analyses of petro- and bioplastic supply chains, offering granular operational insights. Second, it clarifies the limitations of existing SCM models in explaining emergent, compliance-driven systems such as bioplastics. Third, it integrates comparative SCM with dynamic capability theory to demonstrate how adaptive reconfiguration underpins material transition readiness. Collectively, these contributions advance understanding of how firms operationalize sustainability transitions in practice.

2. Literature review

The packaging industry represents a critical arena in which supply chain practices intersect with sustainability imperatives. While petro-plastic supply chains are widely studied in terms of efficiency, scale, and globalization, bioplastic supply chains remain comparatively underexplored, especially at the operational level. This review synthesizes prior research on both material paradigms, petro-plastics and bioplastics, to establish a conceptual foundation for comparative analysis undertaken in this study.

2.1 Defining scope and context

Bioplastics are generally defined as plastics that are either bio-based, biodegradable, or both. In this study, bioplastics refer specifically to industrially compostable materials certified under EN 13432 or ASTM D6400 standards, typically produced from renewable feedstocks such as PLA (polylactic acid) or starch blends (European Bioplastics, 2023). These definitions are crucial because the term “bioplastics” is sometimes used inconsistently in the literature to describe both renewable and non-compostable materials (Findrik & Meixner, 2023). The review therefore limits scope to compostable carrier-bag applications within the packaging sector.

2.2 Petro-plastic supply chains: maturity and efficiency

Petro-plastic supply chains are built upon decades of industrial development, characterized by technological maturity, scale, and global integration. The industry’s upstream-downstream coordination, from resin producers to converters and distributors, has created an optimized system capable of predictable output and quality control (Hopewell et al., 2009).

In sourcing, petrochemical firms benefit from long-term supply contracts and secure feedstock availability, enhanced by shifts such as the North American shale gas boom that diversified polyethylene production (Geyer et al., 2017). Production technologies are refined through innovations in extrusion and catalyst design, enabling thinner, stronger films consistent with circular-economy efficiency goals (Al-

Salem et al., 2009). Distribution is globally standardized through multinational logistics and warehousing systems, allowing just-in-time delivery and minimal disruption (Seuring & Müller, 2008). These integrated characteristics make petro-plastic chains efficient and resilient, though environmentally unsustainable.

2.3 Bioplastic supply chains: fragmentation and transition challenges

Bioplastics, though positioned as sustainable alternatives, face structural constraints across sourcing, production, and distribution. Global production capacity remains below 1 % of total plastics (European Bioplastics, 2023). Sourcing depends on a limited number of certified resin suppliers, largely concentrated in Europe and North America, creating supply bottlenecks for converters in Asia and the Middle East (Di Bartolo et al., 2021). Additional feedstock controversies persist, as the 'food versus fuel' debate, raises ethical questions about large-scale feedstock use (Peelman et al., 2013).

Production challenges include high scrap rates and frequent process adjustments due to resin variability and strict certification requirements (Rujnić-Sokele & Pilipović, 2017). Variations in enforcement of EN 13432 and ASTM D6400 standards across jurisdictions introduce regulatory uncertainty (Van Den Oever et al., 2017). These complexities reduce efficiency and increase costs. Distribution systems remain fragmented: shelf-life constraints, consumer misconceptions, and limited retailer acceptance restrict scalability (Dilkes-Hoffman et al., 2019; Filho et al., 2022). Consequently, bioplastic supply chains lack the maturity, standardization, and resilience of petro-plastics.

2.4 Comparative gaps in the literature

Although extensive research exists on plastics and sustainability, comparative studies of supply chain practices between petro-plastics and bioplastics remain rare. Three gaps are evident:

2.4.1 Operational focus

Most research privileges environmental performance (e.g., LCA) over operational performance (Papong et al., 2014; Walker & Rothman, 2020). The practical realities of sourcing, supplier qualification, and logistics execution are underrepresented.

2.4.2 Firm-level analysis

Studies often adopt macro perspectives such as policy analysis or consumer behavior (Walker et al., 2008; Findrik & Meixner, 2023) but neglect micro-level practices within firms and their supply chains.

2.4.3 Transitional dynamics

There is limited understanding of how operational practices diverge during transitions, such as supplier shifts, process adaptations, and distribution redesign (Seuring & Müller, 2008; Pagell & Wu, 2009) particularly in emerging markets.

Addressing these gaps requires a comparative approach to how firms manage sourcing, production, and distribution within both material paradigms under the pressures of sustainability transition.

2.5 Theoretical anchors: comparative supply chain management and dynamics capabilities

This study integrates comparative supply chain management (SCM) and dynamic capabilities as complementary theoretical lenses.

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From a comparative SCM perspective, cross-industry analysis clarifies how material systems shape operational configurations. Established petro-plastic chains exhibit stability, economies of scale, and efficiency, whereas emergent bioplastic chains face uncertainty, fragmentation, and compliance complexity (Golicic & Sebastiao, 2011; Mentzer et al., 2001).

Dynamic capability theory (Teece et al., 1997; Teece, 2007) explains how firms sense opportunities, seize them through process innovation, and reconfigure resources to adapt. Empirical studies, including Saad et al. (2014) show how such capabilities enable firms in volatile industries to sustain performance. Applying this lens to bioplastics clarifies how firms reconfigure routines to overcome instability, aligning environmental and operational objectives.

2.6 Theoretical synthesis and expected divergences

Table 1. Theoretical lenses and expected difference between petro-plastic and bioplastic supply chains

Theoretical lens	Core proposition	Expected difference between petro- and bioplastic SCM
Comparative SCM	Supply chains built on established infrastructures display stability, efficiency, and scale advantages.	Petro-plastic: mature, cost-efficient, globally integrated networks. Bioplastic: emergent, fragmented, compliance-driven, smaller scale.
Dynamic Capabilities	Firms that can sense, seize, and reconfigure resources perform better under volatility.	Petro-plastic: incremental innovation within stable routines. Bioplastic: ongoing capability reconfiguration (supplier diversification, certification learning, process adaptation).

Table 1 synthesizes the two primary theoretical lenses underpinning this study and clarifies the expected divergences in supply-chain practices between petro-plastic and bioplastic systems. Drawing on comparative supply chain management (SCM), the table highlights how petro-plastic supply chains benefit from established infrastructures, scale efficiencies, and routinized coordination mechanisms, whereas bioplastic supply chains operate under emergent, fragmented, and compliance-driven conditions.

In parallel, the dynamic capabilities lens explains how firms respond differently to volatility across the two material systems. While petro-plastic firms primarily engage in incremental innovation within stable operational routines, bioplastic firms are required to continuously sense environmental and regulatory shifts, seize new technological or organizational opportunities, and reconfigure supply-chain capabilities in areas such as sourcing, certification learning, and process adaptation.

By integrating these lenses, Table 1 provides a structured theoretical foundation for the empirical analysis that follows, linking established theory to the anticipated operational divergences examined in the findings section.

2.7 Summary

The literature establishes clear contrasts between petro-plastic and bioplastic supply chains. Petro-plastics benefit from maturity, efficiency, and global integration, while bioplastics confront sourcing bottlenecks, production instability, and distribution fragmentation. However, empirical comparative research at the firm level remains scarce. This study addresses that gap by applying comparative SCM and dynamic-capabilities frameworks to firm-level data, revealing how operational practices diverge and evolve under material-transition pressures.

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3. Methodology

3.1 Research design

This study adopted a qualitative comparative research design to investigate supply chain practices across petro-plastic and bioplastic carrier-bag industries. A qualitative approach was chosen for its ability to capture rich, contextual insights into firm-level operations that cannot be easily quantified (Yin, 2018).

The comparative logic is not merely descriptive but analytically meaningful, as it enables the identification of patterned similarities and divergences between mature and emergent supply chains (Miles & Huberman, 1994). This cross-paradigm approach allows theory-informed interpretation of how firms adapt practices under different material systems, rather than simple juxtaposition.

The unit of analysis was defined as the firm-level supply chain for carrier-bag applications, with attention to sourcing, production, and distribution. To strengthen validity, data were collected across a diverse set of organizations positioned at different stages of the supply chain, including resin suppliers, converters, retailers, and consultants, ensuring comprehensive coverage of upstream, midstream, and downstream perspectives.

3.2 Sampling and participants

A purposive sampling strategy was used to identify senior industry experts (Marshall, 1996). Criteria for selection included seniority (decision-making responsibility), direct involvement in packaging supply chains, and familiarity with both petro-plastic and bioplastic practices. Recruitment was conducted through professional networks, LinkedIn industry groups, and snowball referrals.

Seventeen participants were interviewed across Europe, Southeast Asia, the Middle East, and Australasia. The cohort comprised:

- Resin and additive suppliers (e.g., executives from petrochemical firms and biopolymer providers).
- Converters/manufacturers (factory managers, production heads).
- Retailers/brand owners (procurement and category buyers).
- Consultants and association representatives.

Table 2 provides demographic details including role, region, and years of experience. The diversity of participants ensured multi-perspective coverage across the supply chain.

3.3 Data collection

Data was collected using semi-structured interviews, guided by an interview protocol following Kallio et al. (2016). The protocol included sections on sourcing practices, production processes, distribution channels, and certification compliance. Questions were open-ended to allow respondents to elaborate on experiences, while probes ensured coverage of targeted areas.

Interviews lasted between 45 and 90 minutes and were conducted face-to-face or via online platforms (e.g., Zoom, MS Teams) depending on participant availability. All interviews were audio-recorded with consent and transcribed verbatim for analysis. No interpreters were required as all participants were fluent in English. Ethical approval was obtained from the hosting university, and anonymity was assured through pseudonymization of participant identities.

Supplementary data sources, including industry reports, company documents, and trade association publications, were used to triangulate findings and provide contextual validation.

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Table 2. Profile of informants

Informant Code	Job Title / Role	Sector / Function	Region	Experience (Years)
INF-01	Managing Director	Manufacturing/Converter	Europe	20+
INF-02	Polyethylene Sales Manager	Resin Supplier	SE Asia	15+
INF-03	Management Consultant	Packaging Industry	SE Asia	25+
INF-04	General Manager	Manufacturing	SE Asia	20+
INF-05	Factory Manager	Manufacturing	South Asia	18+
INF-06	Management consultant	Technical Consultancy	SE Asia	25+
INF-07	Head of Global Marketing	Biopolymer Supply	Europe	20+
INF-08	Consultant	Packaging Industry	Middle East	40+
INF-09	Marketing Consultant	Packaging Industry	South Asia	20+
INF-10	Managing Director	Packaging Industry	SE Asia	25+
INF-11	Managing Director	Additive Supplier	SE Asia	20+
INF-12	Managing Director	Manufacturing/Converter	Middle East	40+
INF-13	CEO	Manufacturing	SE Asia	20+
INF-14	Sales Manager	Manufacturing	SE Asia	12+
INF-15	Buyer	Retail / Procurement	SE Asia	18+
INF-16	Chief Operating Officer	Packaging Industry	FE Asia	30+
INF-17	Factory Manager	Manufacturing/Converter	Middle East	15+

3.4 Data analysis

Data was analyzed using thematic analysis following Braun & Clarke's (2006) six-step thematic analysis framework:

1. Familiarization with transcripts through iterative reading.
2. Generation of initial codes linked to sourcing, production, and distribution.
3. Searching for themes by clustering codes.
4. Reviewing themes to ensure alignment with research objectives.
5. Defining and naming sub-themes.
6. Producing the final narrative, supported with representative quotes.

NVivo 14 software was employed to manage coding, facilitate cross-case comparisons, and visualize thematic structures. Coding was performed by a single researcher, with consistency verified through repeated review and reflection. An audit trail was maintained to record coding decisions and theme evolution.

The final thematic framework yielded three sub-themes: (1) sourcing practices, (2) production configurations, and (3) distribution and channel structures. These form the basis of the findings section.

3.5 Trustworthiness and rigor

To ensure research quality, the study followed Lincoln and Guba's (1985) criteria of credibility, transferability, dependability, and confirmability.

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- Credibility was enhanced through triangulation of data sources (interviews, documents) and member-checking with selected participants.
- Transferability was supported by providing detailed contextual information on cases, enabling readers to judge relevance.
- Dependability was established by maintaining an audit trail of coding decisions and data analysis steps.
- Confirmability was achieved by reflexive journaling, ensuring researcher biases were acknowledged and minimized.

Data saturation was reached by the 15th interview, with no new codes emerging in subsequent interviews, supporting adequacy of sample size (Guest et al., 2006).

A brief positionality statement: The primary researcher has over 20 years of professional experience in global packaging supply chains, offering insider understanding while maintaining reflexive awareness to mitigate potential bias through peer debriefing.

3.6 Ethical considerations

Ethical approval was obtained from the Universiti Teknologi MARA Research Ethics Committee, Ref: REC/09/2025 (PG/MR/489). Participants were provided with information sheets and signed consent forms prior to participation. Anonymity was ensured through pseudonyms, and company identifiers were removed. Data were stored securely in encrypted files, accessible only to the research team. The research adhered to the principles of the Declaration of Helsinki (2013) (World Medical Association, 2013) and the institutional research ethics guidelines.

3.7 Summary

The qualitative comparative methodology provided a robust basis for exploring supply chain practices. By drawing on insights from 17 elite informants across the packaging value chain, triangulated with documentary sources, the study offers credible and context-rich evidence of how petro-plastic and bioplastic supply chains diverge in sourcing, production, and distribution.

4. Findings

This section presents the empirical findings aligned with Research Objective (RO) and Research Question (RQ): *In what salient ways do core supply-chain practices diverge between established petro-plastic and emerging bioplastic carrier-bag supply chains*?

Thematic analysis of 17 elite interviews revealed three interrelated sub-themes: (1) sourcing practices, (2) production configurations, and (3) distribution and channel structures. These sub-themes are interlinked dimensions of the same supply-chain system. Decisions in sourcing directly influence production stability, while both shape distribution reliability. For instance, volatile resin supply in bioplastics leads to production delays and shorter shelf-life, which subsequently affects logistics and order planning. The themes therefore represent sequential yet overlapping stages through which systemic differences manifest across the two material paradigms.

4.1 Divergence in sourcing practices

Sourcing emerged as a critical area of divergence, shaped by differences in supplier availability, certification requirements, and global trade dependencies.

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Petro-plastic supply chains benefit from long-standing procurement systems and established global supplier networks. Supplier audits and qualification procedures are routinised, underpinned by the dominance of major petrochemical firms. These arrangements provide stable supply flows and predictable input quality. As one petrochemical executive explained:

"Carrier bags are a small percentage of polyethylene consumption, but the global system is mature. Supply comes from multiple feedstock sources, whether oil or shale gas, and contracts are stable. We focus more on optimizing cost and reducing carbon footprint rather than worrying about resin availability" (Senior Sales Manager, from a multinational energy firm)

By contrast, bioplastic supply chains are marked by constrained supplier bases, heavy reliance on imports, and volatility in both cost and quality. Firms reported challenges in securing certified compostable resins, with limited global producers able to meet EN 13432 or ASTM D6400 standards. Several respondents highlighted the burden of inconsistent quality:

"Providing a very consistent compostable resin to my customers is always a challenge. One batch may pass certification tests, while another fails elongation or jog tests. Manufacturers end up with dead stock because quality can't be guaranteed." (Managing Director, Additive distributor Malaysia)

Additionally, global sourcing challenges exacerbate risks. Bioplastic resins are often imported from Europe or North America, with long lead times, averaging 8-12 weeks and exposure to trade disruptions. This contrasts with petro-plastics, which enjoy diversified global production footprints and 3-4 weeks of lead-time.

"When customers change from petro-polymers to biodegradable material, procurement and technology shifts are significant. It means new certifications, new suppliers, and higher working capital tied up in imported resin" (International Marketing Consultant from South Asia)

These sourcing-related divergences highlight the resilience of the petro-plastic system, which is built on global integration and established qualification routines, in contrast to the fragility of the bioplastic system. In the latter, reliance on narrow pools of certified suppliers and recurring certification bottlenecks heightens exposure to supply disruption and working-capital risk.

4.2 Divergence in production configurations

Production processes reveal stark contrasts in technological maturity, process stability, and quality compliance.

Petro-plastic manufacturers rely on highly standardized processes optimized for efficiency. Extrusion, film blowing, and printing are supported by decades of technological refinement, enabling firms to deliver consistent throughput and cost competitiveness. Quality control mechanisms are routine and widely harmonized.

"Our product strategy is to deliver the same performance with less material. Technology improvements in catalysts and extrusion help reduce film thickness without compromising strength. It is part of our 'reduce' strategy for sustainability." (Senior Sales Manager, from a multinational energy firm)

In contrast, bioplastic production is hampered by frequent process adjustments and instability. Participants reported higher scrap averaging 12–18%, compared to below 3% in petro-plastics., machinery reconfigurations, and certification-driven trial-and-error. Illustrating these production hurdles, one factory manager noted:

"Switching to compostable film meant line changes and new machine investments. Even then, scrap rates are higher ~15%, and shelf-life constraints make it harder to meet customer quality expectations." (Factory Manager, Packaging converter from UAE)

Quality compliance is a recurring difficulty, with bioplastic resins failing tests for strength, flexibility, or consistency.

"A customer ended up with unusable inventory because compostable film failed elongation and jog tests. These variations come from renewable-source resins, which are less predictable than fossil-based polymers." (Managing Director, Additive distributor Malaysia)

Testing and certification requirements amplify these challenges. While petro-plastics rely on established ISO or ASTM standards, bioplastics must navigate emerging, sometimes conflicting, certification schemes, adding complexity to production planning. Certification testing adds further delays and costs, obtaining EN 13432 or ASTM D6400 compliance can extend product launch timelines up to 9 months.

In production, the divergence is evident between the operational efficiency of the mature petro-plastic system and the instability of bioplastic manufacturing processes. In the latter, variability in bio-based inputs and recurring certification requirements disrupt process consistency, resulting in higher scrap rates and reduced production reliability.

4.3 Divergence in distribution channel structures

Distribution and channel structures diverge in terms of warehousing models, transport logistics, and customer delivery expectations.

Petro-plastic supply chains benefit from extensive global distribution networks. Large-scale warehousing and just-in-time delivery systems are common, supported by partnerships with distributors and importers. Retailers benefit from reliable replenishment and low stock-out risk.

"Major suppliers offer warehousing and distribution for retailers, absorbing inventory carrying costs. This is possible because of scale and predictable demand for conventional bags." (International Marketing Consultant from South Asia)

In contrast, bioplastic distribution is niche and fragmented. Respondents highlighted shelf-life risks in storage, limited regional distribution partners, and cautious retailer adoption. Smaller, more frequent orders dominate due to demand uncertainty and high unit costs.

"With compostable bags, planning is harder. Retailers place smaller, cautious orders because regulations may change, or customers may reject the price. That creates higher warehousing costs and uncertainty for us." (Buyer, from a large supermarket chain in Southeast Asia)

Warehousing presents additional risk: compostable bags degrade under humidity or heat, reducing shelf life to 6–12 months, compared to multi-year stability for petro-plastic bags. This results in 30–40% higher warehousing costs and more frequent distribution cycles. Transport logistics must also manage tighter environmental controls and packaging protections.

Distribution practices further differentiate the two material systems, with petro-plastic supply chains leveraging scale, predictable demand, and established distributor partnerships to support efficient logistics. By contrast, bioplastic distribution remains fragmented, shaped by demand uncertainty, smaller order volumes, and heightened storage and shelf-life risks.

4.4 Cross-case synthesis

Comparative analysis demonstrates systemic divergences between petro-plastic and bioplastic supply chains (Table 3). Petro-plastic practices are mature, integrated, and efficient, while bioplastic practices are emergent, fragmented, and compliance-driven.

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Table 3. Comparative supply chain practices

Sub-theme	Petro-plastics (Established)	Bioplastics (Emergent)
Sourcing practices	Global networks, stable contracts, diversified feedstocks	Limited suppliers, import dependence, certification bottlenecks
Production configurations	Mature processes, low scrap (<3%), consistent QA, predictable output	Frequent reconfiguration, high scrap (12-18%), certification delays (6-9 months), unstable quality
Distribution structures	Scalable warehousing, global partnerships, predictable demand	Niche channels, small/cautious orders (25% of normal volumes), shelf-life/storage risks (6-12 months)

To visualize how these interdependencies form a systemic pattern, Figure 1 illustrates how weaknesses in sourcing cascade through production and distribution processes.

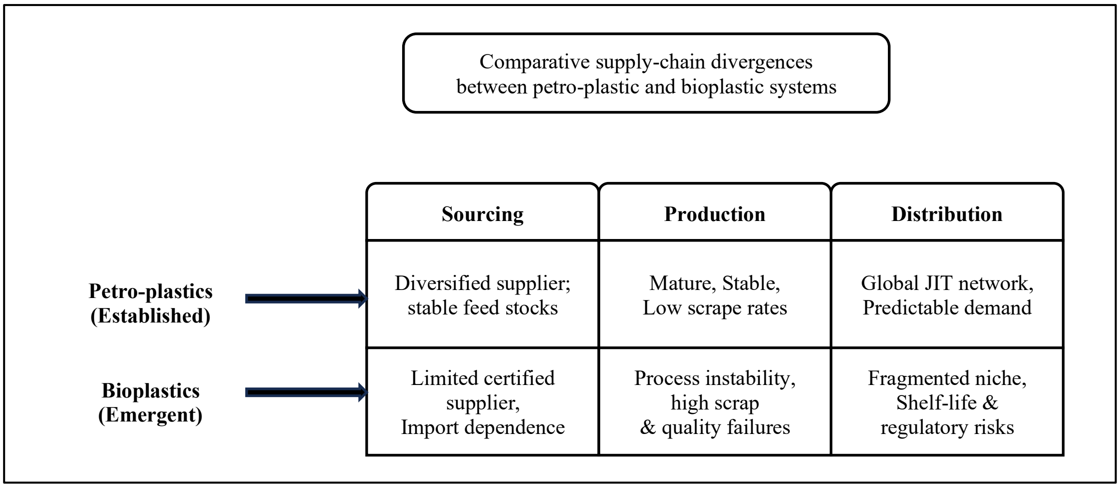

Figure 1. Comparative supply chain divergences between petro-plastic and bioplastic systems

4.5 Summary of findings

Taken together, the findings demonstrate a fundamental divergence in supply chain practices between petro-plastic and bioplastic carrier-bag systems. While petro-plastic supply chains are characterized by maturity, resilience, and operational efficiency, bioplastic supply chains operate under conditions of fragility, volatility, and compliance-driven uncertainty, requiring firms to actively redesign procurement, production, and distribution practices.

5. Discussion

The findings of this study provide the first empirical comparison of supply chain practices between petro-plastic and bioplastic carrier-bag industries. Three sub-themes, sourcing, production, and distribution, revealed systemic divergences rooted in differences in supply maturity, technological readiness, and institutional context. This section interprets these divergences through the lens of supply chain management

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(SCM) and comparative operations theory, situates the results within the extant literature and outlines the study's theoretical and managerial contributions.

5.1 Interpreting divergent sourcing practices

Sourcing emerged as a central point of divergence. Petro-plastic supply chains operate on long-established procurement infrastructures characterized by diversified feedstocks, standardized supplier audits, and economies of scale. These features reflect cumulative learning and capability development across decades (Hopewell et al., 2009). Bioplastic supply chains, in contrast, are constrained by narrow supplier bases and certification bottlenecks. This fragility aligns with research on emerging sustainable supply chains, where institutional immaturity and inconsistent input quality inhibit scales (Golicic & Sebastiao, 2011).

The mechanism underlying this divergence is that certification volatility directly restricts sourcing flexibility. Because each supplier must hold EN 13432 or ASTM D6400 certification, firms cannot easily substitute inputs during supply disruptions. This rigidity magnifies risk and delays, forcing managers to develop dynamic capabilities such as supplier scouting, joint certification programs, and pre-qualification with multiple resin providers.

From a managerial standpoint, diversification through *multi-source procurement, regional certification partnerships, and information sharing* with resin producers can enhance supply resilience and reduce working-capital exposure.

5.2 Production configurations and process instability

The study revealed sharp contrasts in production practices between petro-plastic and bioplastic supply chains. Petro-plastic processes are technologically mature and stable, benefiting from decades of refinement in catalysts, extrusion, and film-blowing technologies that reduce material use without compromising performance. These innovations align with the “reduce” principle of the circular economy (Al-Salem et al., 2009) and exemplify dynamic capabilities that continuously enhance efficiency through incremental process improvements.

Bioplastic production, however, is characterized by process instability. Firms reported higher scrap rates, frequent line reconfigurations, and unpredictable test results. This finding is consistent with Peelman et al. (2013), who observed variability in mechanical performance, and Rujnić-Sokele and Pilipović (2017), who emphasized certification-driven challenges in scaling production. Such instability undermines cost competitiveness and reinforces barriers identified in prior reviews of bioplastic adoption (Di Bartolo et al., 2021).

Theoretical interpretation suggests that certification volatility and resin inconsistency trigger repeated reconfiguration cycles, compelling firms to sense (identify resin variability), seize (invest in modular equipment), and reconfigure (adjust production routines), the three micro foundations of dynamic capabilities (Teece et al., 1997).

Empirical parallels exist in other volatile industries such as oil and gas, where firms developed adaptive supply chain routines to sustain performance amid feedstock uncertainty (Saad et al., 2014). The same logic applies here: bioplastic converters must continuously realign operational routines as regulatory and material parameters evolve.

Managerially, the implication is clear: firms should prioritize adaptive process innovations and invest in modular machinery, real-time process monitoring, and adaptive quality control systems to shorten certification cycles and improve cost efficiency.

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5.3 Distribution structures : scale vs fragmentation

Distribution further reinforces the divergence. Petro-plastic supply chains are globally integrated, leveraging warehousing models, distributor partnerships, and just-in-time delivery systems. These practices reflect maturity, scale, and retailer acceptance. By contrast, bioplastic supply chains remain fragmented and niche, constrained by demand uncertainty, cautious retailer orders, and shelf-life risks.

From a theoretical standpoint, this illustrates how institutional pressures (regulations, customer expectations) shape distribution viability. Whereas petro-plastics benefit from institutional inertia and infrastructure lock-in, bioplastics face constant pressure to prove legitimacy in logistics systems (DiMaggio & Powell, 1983).

For practitioners, the implication is clear: bioplastic distribution requires collaborative risk-sharing with retailers. Mechanisms such as vendor-managed inventory, consignment stock, or flexible contracting may mitigate volatility in demand and reduce warehousing burdens.

5.4 Comparative framework: petro-plastics vs bioplastics

Synthesizing across sourcing, production, and distribution, a comparative framework emerges (refer to Figure 2 below). This framework illustrates how operational divergence is not random but systematically driven by external uncertainty when interacting with internal capability gaps. Petro-plastic supply chains represent "mature-stability equilibrium," while bioplastic chains operate in "adaptive-transitional equilibrium." The latter requires dynamic capability development to bridge institutional and technical uncertainty.

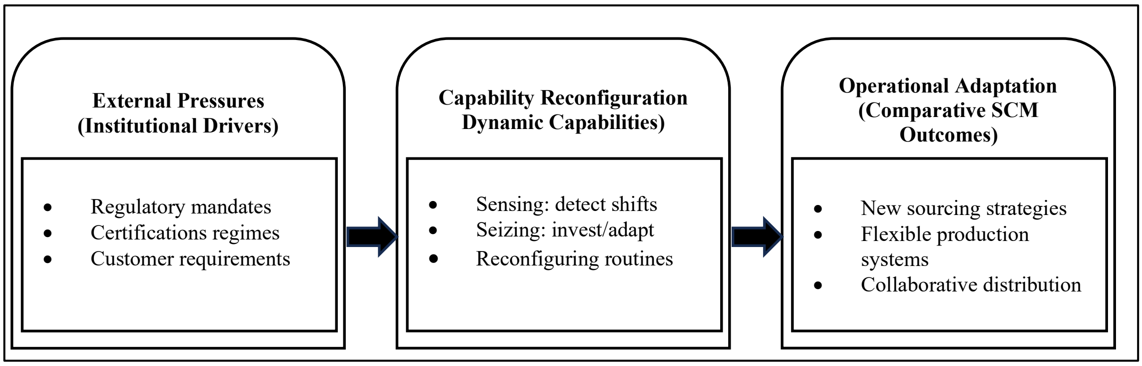

Figure 2. Conceptual framework: Divergence–Mechanism–Managerial response in supply chain transition.

5.5 Theoretical contributions

This study makes several important contributions to theory by extending and integrating perspectives from comparative supply chain management, dynamic capabilities, and institutional theory within the context of sustainability-driven material transitions. First, it advances comparative supply chain management (SCM) scholarship by providing rare firm-level empirical evidence on how material substitution reshapes operational practices. While prior research on plastics has largely focused on environmental performance metrics such as life-cycle assessment or on consumer perceptions of sustainable packaging (Papong et al., 2014; Spierling et al., 2018), this study shifts attention to the internal workings of supply chains. By comparing petro-plastic and bioplastic systems, it demonstrates that sustainability transitions are not merely technological or environmental challenges, but fundamentally operational transformations that generate distinct sourcing, production, and distribution logics.

Second, the study extends dynamic capabilities theory by illustrating how certification volatility, material inconsistency, and regulatory uncertainty act as triggers for capability reconfiguration in emergent supply chains (Teece, 2007). The findings show that firms operating in bioplastic systems must continuously engage in sensing (identifying changes in certification regimes or resin quality), seizing (investing in new processes, equipment, or supplier relationships), and reconfiguring (adjusting routines and operational structures) to stabilize performance. In contrast to petro-plastic supply chains, where dynamic capabilities largely support incremental innovation within stable routines, bioplastic supply chains require ongoing and deliberate reconfiguration. This application broadens the relevance of dynamic capabilities beyond competitive strategy into the domain of sustainability transitions and material innovation.

Third, the study contributes to institutional theory by demonstrating how legitimacy-seeking behaviors mediate the operational viability of emerging sustainable supply chains (DiMaggio & Powell, 1983). The reliance on certification schemes, transparency mechanisms, and close collaboration with retailers reflects efforts by bioplastic firms to gain acceptance within established market and regulatory structures. These findings highlight how institutional pressures—such as regulatory mandates and customer expectations—interact with operational constraints to shape supply chain practices. In doing so, the study shows that supply chain evolution in sustainable materials is not only a function of efficiency or technology, but also of institutional alignment and legitimacy building.

Taken together, these contributions offer an integrated theoretical explanation of how firms navigate sustainability transitions at the operational level. By combining comparative SCM, dynamic capabilities, and institutional perspectives, the study provides a more holistic understanding of why petro-plastic and bioplastic supply chains diverge, and how firms attempt to bridge these divergences through capability development and institutional adaptation.

5.6 Managerial implications

The findings of this study offer several important implications for managers navigating the transition from petro-plastic to bioplastic supply chains. Most critically, the results underscore that bioplastics cannot be managed as a simple material substitute within existing petro-plastic supply chain systems. Instead, managers must recognize bioplastic supply chains as emergent and volatility-prone systems that require deliberate redesign across sourcing, production, and distribution functions. Treating bioplastics as a like-for-like replacement risks underestimating certification constraints, quality variability, and demand uncertainty. These risks can undermine both operational performance and sustainability objectives.

From a sourcing perspective, managers should prioritize supplier diversification and collaborative certification strategies to mitigate availability and quality risks. Given the limited pool of certified bioplastic resin suppliers and the rigidity imposed by standards such as EN 13432 and ASTM D6400, firms are highly exposed to supply disruptions and working-capital lock-in. Developing multi-sourcing arrangements, engaging in joint certification programs with resin producers, and sharing testing data across the supply base can enhance sourcing resilience and reduce dependency on single suppliers. These practices align with prior research on supply chain development in nascent markets, which emphasizes proactive supplier engagement as a mechanism for reducing uncertainty (Golicic & Sebastiao, 2011).

In production, the evidence points to the need for greater operational flexibility rather than further efficiency optimization alone. Higher scrap rates, frequent line reconfigurations, and certification-driven testing cycles suggest that conventional efficiency-oriented manufacturing models are insufficient in bioplastic contexts. Managers should therefore invest in modular machinery, adaptable processing lines, and advanced quality-control systems that enable rapid adjustment to resin variability and evolving certification requirements. Such investments reflect the development of dynamic capabilities, allowing firms to sense material instability, seize process improvement opportunities, and reconfigure production routines as conditions change (Teece et al., 1997; Teece, 2007). Over time, these adaptive capabilities can help narrow the performance gap between bioplastic and petro-plastic operations.

Distribution and logistics strategies also require reconsideration. The findings show that demand uncertainty, shelf-life constraints, and cautious retailer adoption make traditional large-scale warehousing and push-based distribution models less viable for bioplastics. Managers should therefore pursue collaborative risk-sharing mechanisms with downstream partners, such as vendor-managed inventory, consignment stock, or joint forecasting arrangements. These approaches can help stabilize order patterns, reduce inventory obsolescence, and distribute risk more equitably across the supply chain, consistent with sustainable supply chain practices identified by Seuring and Müller (2008).

Strategically, the study highlights the importance of ambidextrous supply chain management during sustainability transitions. Managers must simultaneously maintain efficiency and reliability in mature petro-plastic operations while investing in flexibility, learning, and experimentation within bioplastic supply chains. This dual focus enables firms to meet short-term commercial pressures while building the capabilities required for long-term regulatory compliance and sustainability leadership. Recognizing and managing this tension is essential for firms seeking to scale bioplastics without compromising operational viability.

5.7 Limitation and future research

This study has several limitations that should be acknowledged. First, the qualitative research design, while well suited for generating rich, firm-level insights, limits the statistical generalizability of the findings. Second, the focus on operational practices within firms does not fully capture broader macro-level forces that also shape the viability of petro-plastic and bioplastic supply chains. These forces can be either fluctuations in oil prices, agricultural feedstock markets, or government subsidy regimes. Third, although the study draws on informants from multiple regions, the geographic coverage remains selective, which may constrain the transferability of findings to regions with different regulatory, infrastructural, or market conditions.

These limitations open several avenues for future research. Quantitative studies could test and validate the patterns identified here using large-scale surveys or performance data across a wider set of firms and regions. Longitudinal research would be particularly valuable in tracing how dynamic capabilities and operational practices evolve as bioplastic supply chains mature and regulatory frameworks stabilize. In addition, comparative policy-oriented studies could examine how differences in national or regional regulatory environments accelerate or hinder supply chain transitions, This would enrich understanding of the institutional conditions under which sustainable materials can be scaled effectively.

This study is not without limitations. First, its qualitative scope restricts generalizability, though the richness of elite interviews provides analytical depth. Second, the focus on firm-level practices does not capture broader macroeconomic dynamics (e.g., oil price shocks, agricultural subsidies) that also affect material transitions. Third, the geographic spread, while diverse, was limited to selected regions, leaving scope for further cross-continental comparisons.

6. Conclusion

This study addressed a critical gap in sustainable operations by providing empirical, firm-level evidence on how supply chain practices diverge between petro-plastic and bioplastic carrier-bag industries. The research demonstrates that these divergences—rooted in sourcing constraints, production instability, and fragmented distribution—are outcomes of both technological immaturity and institutional volatility. While petro-plastic supply chains leverage cumulative learning and global integration, bioplastics must build legitimacy and dynamic capability from the ground up.

In addressing the research question, we postulated that core supply-chain practices diverge because bioplastics operate under high material, regulatory, and legitimacy uncertainty, compelling firms to continually reconfigure sourcing, production, and distribution capabilities to achieve stability.

The study contributes conceptually by integrating comparative SCM, dynamic capabilities, and institutional theory into a single framework explaining sustainability transitions. Practically, it offers a roadmap for firms to manage these transitions through supplier diversification, flexible production systems, and collaborative distribution models.

While qualitative and regionally bound, this research lays the foundation for future mixed-method and longitudinal inquiries into the evolution of sustainable supply chains. In summary, bridging the efficiency of petro-plastics and the sustainability promise of bioplastics requires not only technological innovation but also institutional alignment and capability reconfiguration across the value chain. Understanding these dynamics is vital for achieving scalable and credible sustainability transitions in global packaging systems.

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Conflict of interest statement

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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Ayoub Danka carried out the research, wrote and revised the article. Shatina Saad supervised research progress anchored the review, revisions and approved the article submission.